JAPAN

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

The Japan Meteorological Agency (JMA) carries out total column ozone and Umkehr measurements at four sites in Japan (Sapporo, Tsukuba, Naha and Minamitorishima) and at Syowa Station in Antarctica (Table 1). A Brewer spectrophotometer is used for measurements at Minamitorishima, whereas Dobson spectrophotometers are used at the other observation sites.

Table 1. Locations of column ozone and Umkehr measurement sites operated by JMA

Observation site	Latitude	Longitude	Altitude (m)	WMO station number
Sapporo	43° 04′ N	141° 20′ E	26	47412
Tsukuba	36° 03′ N	140° 08′ E	31	47646
Naha	26° 12′ N	127° 41′ E	28	47936
Minamitorishima	24° 17′ N	153° 59′ E	9	47991
Syowa	69° 00′ S	39° 35’ E	22	89532

Concentrations of ozone-depleting substances and other constituents are monitored by the Center for Global Environmental Research (CGER) of the National Institute for Environmental Studies (NIES) and by JMA. The monitoring sites are listed in Table 2. CGER/NIES monitors halocarbons (CFCs, CCl_4, CH_3CCl_3 and HCFCs), HFCs, surface ozone, CO_2, CH_4, CO, N_2O, NO_x, H_2, O_2/N_2 ratio, and aerosols at remote sites (Hateruma and Ochiishi). JMA measures surface concentrations of ozone-depleting substances (CFCs, CCl_4 and CH_3CCl_3) and other constituents (surface ozone, CO_2, N_2O, CH_4 and CO) at Ryori, a Global Atmosphere Watch (GAW) Regional Station in northern Japan. Monitoring of concentrations of surface ozone, CO_2, CH_4 and CO is also carried out at Minamitorishima (a GAW Global Station) and Yonagunijima (a GAW Regional Station in the Ryukyu Islands).

The Japanese Ministry of the Environment (MOE) monitors concentrations of halocarbons (CFCs, CCl_4, CH_3CCl_3, halons, HCFCs and CH_3Br) and HFCs at remote sites (around Wakkanai and Nemuro) and at an urban site (Kawasaki).

Table 2. Locations of monitoring sites for ozone-depleting substances and other minor constituents

Monitoring site	Latitude	Longitude	Altitude (m)	Since	Organization
Ochiishi	43° 10′ N	145° 30′ E	45	Oct 1995	CGER/NIES
Hateruma	24° 03′ N	123° 49′ E	10	Oct 1993	CGER/NIES
Ryori	39° 02′ N	141° 49′ E	260	Jan 1976	JMA
Minamitorishima	24° 17′ N	153° 59′ E	8	Mar 1993	JMA
Yonagunijima	24° 28′ N	123° 01′ E	30	Jan 1997	JMA
Syowa	69° 00′ S	39° 35′ E	18	Jan 1997	JMA

JMA also monitors CFCs, CO_2, N_2O and CH_4 concentrations in both the atmosphere and seawater of the western Pacific onboard the research vessels *Ryofu Maru* and *Keifu Maru*.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

1.2.1 Ground-based and sonde measurements

Since October 1990, CGER/NIES has measured vertical profiles of stratospheric ozone over NIES in Tsukuba with an ozone laser radar (ozone lidar). After comparison with JMA ozone sonde data and Stratospheric Aerosol and Gas Experiment II (SAGE II) ozone profiles, the ozone lidar data were accepted by the Network for the Detection of Atmospheric Composition Change (NDACC) and registered in the NDACC database. CGER/NIES began measuring vertical profiles of ozone with millimetre-wave radiometers in September 1995 at Tsukuba and in March 1999 at Rikubetsu.

JMA has been monitoring the vertical ozone distribution weekly by ozone sonde at three sites in Japan and at Syowa Station in Antarctica. The ECC type ozone sonde succeeded the KC type in October 2008 at Naha, in November 2009 at Sapporo and Tsukuba, and in March 2010 at Syowa. The KC sonde was developed by JMA and has been used in Japan since the 1960s.

1.2.2 Airborne measurements

In February 2011, JMA began taking monthly (approx.) airborne in situ measurements of CO_2, CH_4, CO and N_2O concentrations at an altitude of about 6 km along the flight path from Tokyo area to Minamitorishima.

1.2.3 Satellite measurements

Ozone-layer depletion in high-latitude regions was monitored with the Improved Limb Atmospheric Spectrometer (ILAS), a satellite-borne solar-occultation sensor, from August 1996 to June 1997. ILAS-II (the successor to ILAS) was used to measure concentrations of minor constituents associated with polar ozone depletion from April to October 2003. These data were processed and analyzed at NIES. Version 6.1 ILAS data, which include O_3, HNO_3, NO_2, N_2O, CH_4, H_2O, $ClONO_2$, CFC-12 and aerosol extinction coefficients, were released in 2005. Version 2 ILAS-II data, including O_3, HNO_3, N_2O, CH_4, H_2O, $ClONO_2$ and aerosol extinction coefficients, were released in February 2008.

The Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) was developed for deployment in the Japanese Experiment Module (JEM) on the International Space Station (ISS) through the cooperation of the Japan Aerospace Exploration Agency (JAXA) and the Japanese National Institute of Information and Communications Technology (NICT). SMILES was successfully launched by an H-IIB rocket with the H-II Transfer Vehicle (HTV) on 11 September 2009 (all dates are JST). It was attached to the JEM on 25 September and began atmospheric observations on 12 October. The mission objectives are (1) to demonstrate the viability in the outer space environment of a 4-K mechanical cooler and superconducting mixers for submillimetre limb-emission sounding in frequency bands 624.32–626.32 GHz and 649.12–650.32 GHz and (2) to take global measurements of atmospheric concentrations of minor constituents (O_3, HCl, ClO, HO_2, HOCl, BrO, O_3 isotopes, HNO_3, CH_3CN, etc.) in the middle atmosphere to gain a better understanding of the factors and processes, including climate change, that control the amounts of stratospheric ozone.

Unfortunately, SMILES observations have been suspended since 21 April 2010 owing to the failure of a critical component in the submillimetre local oscillator. Until operations were suspended, SMILES was recording global observations at about 100 locations per ISS orbit, except when other ISS operations took precedence. Processing of SMILES data provides global and vertical distributions of about 10 atmospheric minor constituents related to ozone chemistry, which contribute to resolving a number of current issues in atmospheric science.

1.3 UV measurements

1.3.1 Broadband measurements

CGER/NIES has been monitoring surface UV-A and UV-B radiation using broadband radiometers at four observation sites in Japan since 2000. CGER calculates the UV Index from the observed data and makes it available hourly to the public via the Internet.

1.3.2 Spectroradiometers

JMA monitors surface UV-B radiation with Brewer spectrophotometers at Sapporo, Tsukuba and Naha in Japan and at Syowa Station in Antarctica. Observations commenced in 1990 at Tsukuba and in 1991 at the other sites.

1.4 Calibration activities

JMA has operated the Quality Assurance/Science Activity Centre (QA/SAC) and the Regional Dobson Calibration Centre (RDCC) under the GAW programme of the World Meteorological Organization (WMO) to contribute to improving the quality of ozone observations in WMO Regional Associations II (Asia) and V (South-west Pacific). The Regional Standard Dobson instrument (D116) is calibrated against the World Standard instrument (D083) every three years. The most recent calibration was in 2010 at Mauna Loa, Hawaii, USA. Through the QA/SAC, a JMA expert visited the ozone observatory in Manila in April 2010 to calibrate the Dobson spectrophotometer there and provide training in measurement and maintenance of the instruments used there to monitor the ozone layer. JMA supported installation of automated observation systems for Dobson instruments at NOAA/ESRL, Boulder (May 2009), at Mauna Loa (June 2010), at the Bureau of Meteorology, Melbourne, Australia (August 2010), and at the National Meteorological Service, Buenos Aires, Argentina (November 2010).

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Ozone mixing ratios measured with the millimetre-wave radiometer at Rikubetsu Station from November 1999 to June 2002 agreed well with ozone sonde data from Sapporo and satellite data from the Halogen Occultation Experiment (HALOE).

Trend analysis (eliminating solar activity and quasi-biennial oscillation (QBO) components) of ozone concentrations recorded between 30 and 40 km altitude by laser radar at NIES, Tsukuba, show a significant decreasing trend from 1988 to 1997 (−6.0 percent per decade), but no significant trend after 1998.

Trend analyses for total ozone concentrations at three sites (Sapporo, Tsukuba and Naha), eliminating solar activity and QBO, have shown an overall decrease of total ozone during the 1980s but, in spite of large year-to-year variations, either no significant change or slight increasing trends since the mid-1990s. Vertical profiles from Umkehr and ozone sonde measurements show reduced ozone levels at altitudes of about 20 and 40 km from 1979 to 2009 at Sapporo and Tsukuba, but an increasing trend at altitudes of less than 15 km from 1998 to 2009 at Naha.

Significant increasing trends in erythemal UV measurements have been observed at three sites in Japan (Tsukuba, Naha and Sapporo) since JMA started monitoring UV radiation in the early 1990s. The increasing trend diminished in early 2000s at Tsukuba and Naha, but continues at Sapporo. The increase of erythemal UV radiation since 1990 cannot be attributed to a reduction of ozone levels because they ceased to decline after the mid-1990s.

3. THEORY, MODELLING AND OTHER RESEARCH

The Centre for Climate System Research (CCSR, now the Division of Climate System Research within the Atmosphere and Ocean Research Institute), the University of Tokyo and NIES developed a chemistry–climate model (CCSR/NIES CCM). JMA's Meteorological Research Institute (MRI) independently developed another chemistry–climate model (MRI-CCM). Both the CCSR/NIES and the MRI groups participated in the second round of the Chemistry–Climate Model Validation Activity (CCMVal-2) of the Stratospheric Processes and their Role in Climate (SPARC) programme, and contribute to comparisons between and improvement of CCMs, leading to a better understanding of the individual strengths of these models. The CCSR/NIES and MRI CCMs were used to simulate the recent past and future evolution and global distribution of the stratospheric ozone layer by using concentrations of greenhouse gases and ozone depletion substances as recommended by CCMVal-2. The results of the simulations were published in the SPARC-CCMVal Report (2010). Scientific papers based on the outcome of the simulations were published in a special issue of the *Journal of Geophysical Research*, and will be published in the WMO Ozone Assessment Report 2010. The distribution of chemical species of the CCSR/NIES CCM was used as a priori data for processing of SMILES data.

NIES is developing a new version of its CCM with T42 horizontal resolution, constructed on the MIROC 3.2 AGCM, which was used for future projections of climate for the IPCC fourth Assessment Report. This model has a new radiation code that greatly reduces the problem in the previous model of cold bias in the tropical upper troposphere/lower stratosphere. The new CCM incorporates more stratospheric water vapour than the previous version and better represents observed data. The new CCM is also used as a three-dimensional chemical transport model (CTM) in which temperature and wind velocity data are assimilated into the calculated fields in the model using a nudging method. The model simulates the global distribution of chemical species observed by SMILES.

JMA's MRI has developed both a CTM and CCM for study of stratospheric ozone. A prominent feature of the MRI-CCM is that QBO, which plays a crucial role in inter-annual variations in the stratosphere, is spontaneously reproduced for wind and ozone in the tropical stratosphere by a T42L68 version that has about 300 km of horizontal resolution and 500 m of vertical resolution in the stratosphere. The MRI-CCM has been used at JMA to simulate ozone distributions by incorporating total ozone data from Total Ozone Mapping Spectrometers (TOMS) and Ozone Monitoring Instruments (OMI) and has produced ozone forecasts for several days. The ozone distributions calculated are used to monitor variations in total and stratospheric ozone, as well as for a UV forecast service. MRI-CCM is also used for research on the effect of the ozone layer on climate, as well as for predictions of the future state of the ozone layer.

The MRI-CCM has been further developed (MRI-CCM2) by incorporating tropospheric chemistry to provide a seamless chemistry module from the Earth's surface to the top of the model at about 80 km altitude. MRI-CCM2 is an important component of the MRI earth-system model, which includes the ocean, atmosphere, cryosphere and biosphere.

ILAS and ILAS-II data have been used extensively to elucidate in detail the chemical and physical processes related to ozone layer depletion in polar regions, such as polar stratospheric cloud (PSC) formation, denitrification, chemical ozone loss rates and partitioning among chlorine species.

The effects of enhanced UV-B radiation on terrestrial plants are being studied by NIES, which has developed a novel method of detecting plant UV-B stresses by identifying mRNA expression changes by cDNA macroarray analysis. This method illustrates shifts in gene expression in response to stressors such as drought, salinity, UV-B, low temperature, high temperature, acid rain and photochemical oxidants. Changes in gene expression patterns after UV-B stress accord well with those after ozone exposure, suggesting that physiological responses to UV-B in plant cells may include active oxygen species. UV-B directly damages macromolecules such as proteins and nucleic acids. DNA damage due to UV-B is thought to not only impede DNA replication and gene expression but also lead to mutations. NIES identified that the repair system for UV damaged DNA is controlled by UVB-driven transcriptional activation of the repair enzyme.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

NIES and the Solar-Terrestrial Environment Laboratory (STEL) of Nagoya University have established stations at Tsukuba and Rikubetsu with NDACC instruments, including lidars, millimetre-wave radiometers and FTIR spectrometers. Some of the activities of these organizations have been incorporated into NDACC measurements in Japan. Reanalyzed NIES ozone lidar data are registered in the NDACC database every year. Vertical profiles of ozone recorded by the NIES/STEL lidar have been used to validate ENVISAT data such as SCIAMACHY, MIPAS and GOMOS.

Observational data acquired at JMA's stations are submitted monthly to the World Ozone and UV Data Centre (WOUDC) in Toronto, Canada. Provisional total ozone data are also delivered daily on the Character Form for the Representation and Exchange of Data (CREX) through the WMO Global Telecommunication System (GTS), and used at the WMO Ozone Mapping Centre in Thessaloniki, Greece, to map the total ozone distribution over the Northern Hemisphere. In the Antarctic winter and spring seasons, total ozone and ozone sonde data acquired at Syowa Station are submitted weekly to the WMO Secretariat for incorporation in Antarctic Ozone Bulletins.

4.2 Information to the public

An annual report on the state of the ozone layer, surface UV-B radiation and atmospheric concentrations of ozone-depleting substances is published by the Japanese MOE.

Data summaries of JMA's total ozone, ozone sonde and UV-B measurements are published monthly on the Internet. An annual report that includes detailed trend analyses of ozone over

Japan and the globe is also published for both government and public use. Since 2005, JMA has been providing an Internet UV forecast service (in the form of an hourly UV-index map) based on UV-B observations and ozone forecast modelling techniques. Analytical UV maps and quasi-real-time UV observations are also posted hourly on the website.

4.3 Relevant scientific papers

The MOE supports research on global environmental changes (including ozone layer depletion) through the GERF, and their results are published in their Annual Summary Reports.

5. PROJECTS AND COLLABORATION

As a GERF-funded activity, a project named *Studies on the Variability of Stratospheric Processes and Uncertainties in the Future Projection of Stratospheric Ozone* is being jointly undertaken by NIES, CCSR, Hokkaido University and Miyagi University of Education. Some highlights of the results of this project are as follows.

(1) Tropical lower stratospheric water vapour at 19–21 km altitude was high and increasing in the 1990s, low between 2000 and 2003, and then increased to the level of late 1990s in the mid-2000s.

(2) Gravitational separation in the stratosphere has been identified for the first time from analyses of O_2 and N_2 isotopes in individual air samples.

(3) A set of high-quality CO_2 and SF_6 observations from the middle stratosphere of the Northern Hemisphere mid-latitudes suggest that the age of air in this region has been relatively constant since 1975.

(4) Numerical experiments using the CCSR/NIES CCM showed that ozone recovery to the 1980 level was advanced by at least 10 years in response to future increases of GHGs, but the size of the advance was dependent on latitude.

(5) Analyses of observation data and CCSR/NIES CCM outputs indicate that the ozone hole

influences the timing of the Antarctic polar vortex breakup in austral spring.

JMA's Aerological Observatory has developed an automated Dobson measuring system that reduces the burden on the operator and improves data quality (described on the JMA web site at http://gaw.kishou.go.jp/wcc/dobson/windobson.html). JMA has provided technical support to some foreign organizations interested in introducing this automated Dobson system.

6. FUTURE PLANS

JMA has commenced archiving historical raw ozone records (e.g., R-values and related calibration information) from Dobson spectrophotometers at Sapporo, Tsukuba, Naha and Syowa. Archiving is planned for completion by 2013, which will allow retrospective re-evaluation and reprocessing of historical ozone records in view of changes such as those of ozone absorption cross sections.

Ongoing monitoring of levels of ozone, water vapour and other species near the tropical tropopause will continue to improve our understanding of the role of the tropical transition layer in chemistry–climate interactions. Precise measurements of the concentrations of trace gases in the stratosphere will continue to provide key information on physical, chemical and dynamic processes in the stratosphere. For example, precise monitoring of trace gases in the middle atmosphere enables identification of variability in the mean age of air and evaluation of the ability of current models to reproduce changes in dynamic atmospheric processes.

Development and improvement of CCM and CTM numerical models will continue, which will allow better prediction of future changes to the ozone layer and improve our understanding of the mechanisms of the chemistry–climate interaction. A regular CCM update based on the newest global circulation model would be necessary for research of climate–chemistry interaction.

7. NEEDS AND RECOMMENDATIONS

Processing and reporting to WOUDC of a long record of unprocessed Brewer Umkehr data from Minamitorishima are needed. For Brewer instruments, a selection method for cloud-free "good" data from unattended observations is needed as are side-by-side comparisons with Dobson instruments.

Systematic observations to evaluate the changing state of the ozone layer, including detection of ozone layer recovery, should be continued in cooperation with international monitoring networks such as NDACC and the WMO/GAW programme.

Integration of stratospheric and climate models is desirable to allow more precise prediction of future changes in the ozone layer. The interactions between climate change and ozone layer depletion and changes in the ozone layer in the post-CFC period due to emissions of CH_4, H_2 and N_2O need to be assessed. Studies on chemical and dynamic processes, including the formation of PSCs and denitrification mechanisms, cross-tropopause transport and the ozone budget near the tropopause region should also be continued. Re-evaluation of chemical reaction data, including photochemical data for stratospheric modelling, is urgently required to resolve discrepancies between observations and model calculations.

A systematic calibration program and well-coordinated monitoring network should be established to detect variations and long-term trends in ground-level UV radiation.

Studies on the effects of increased UV radiation on human health, ecosystems, air quality and biogeochemical cycles are strongly recommended, especially the effects of increased UV radiation under rising temperature conditions.